Fractionation of Barley Flour Using Elusieve Processing: A Combination of Sieving and Air Classification

R. Srinivasan, K. B. Hicks, R. K. Challa, J. Wilson, M. Kurantz, R. A. Moreau

Abstract. *The availability of winter barley in areas of the U.S. that are not well suited to grow corn, such as the mid-Atlantic states, makes it a feedstock of choice for fuel ethanol production in those regions. Recently, it was found that the Elusieve process, the combination of sieving and air classification (elutriation or aspiration), was effective in fiber separation from corn flour prior to fermentation. The objective of this study was to determine the effect of the Elusieve process on the compositions of fractions from barley flour of a hulled (Thoroughbred) and a hulless (Doyce) barley variety. The barley grains were milled using a hammer mill and sieved into four size fractions. Air classification of the two largest size fractions using a commercial aspirator resulted in heavier fractions with higher starch, higher beta-glucan, and lower neutral detergent fiber (NDF) contents. Hulls were preferentially carried into the lighter fractions, as signified by higher NDF contents of lighter fractions. Elusieve processing was more effective (higher separation factors) for the hulled variety than the hulless variety because higher hull presence caused increased carryover of hull into the lighter fractions for the hulled variety. The increase in beta-glucan and starch contents in barley flour, by hull separation using the combination of sieving and air classification, may increase ethanol productivity and may be beneficial in fuel ethanol production from barley when using a process that converts both starch and beta-glucans into fuel ethanol. Since the Elusieve process was most effective only when hulls were present, any dehulling operation prior to grinding would make Elusieve processing needless.*

Keywords. *Air classification, Barley, Elusieve, Elutriation, Ethanol, Sieving.*

Fuel ethanol production from cereal grains such as corn and milo (grain sorghum) is increasing rapidly due to the need for energy independence (RFA, 2008). Most U.S. fuel ethanol plants are currently located in the Midwest because of their close proximity to corn production and the resulting low transportation cost. The availability of winter barley, which can be grown on winter fallow land between corn and soybean rotations, in areas of the U.S. with mild winters (such as the mid-Atlantic states) makes it a feedstock of choice for fuel ethanol production in those regions. Growing barley by this means does not interfere with food crop production and actually improves soil quality and water retention by acting as a cover crop (Nghiem et al., 2008).

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The authors are **Radhakrishnan Srinivasan, ASABE Member Engineer,** Assistant Research Professor, Department of Agricultural and Biological Engineering, Mississippi State University, Mississippi State, Mississippi; **Kevin B. Hicks,** Research Leader, Crop Conversion Science and Engineering, USDA-ARS Eastern Regional Research Center, Wyndmoor, Pennsylvania; **Ravi K. Challa,** Graduate Research Assistant, Department of Agricultural and Biological Engineering, Mississippi State University, Mississippi State, Mississippi; and **Jhanel Wilson,** Chemical Engineer, **Michael Kurantz,** Supervisory Chemist, and **Robert A Moreau,** Research Chemist, Crop Conversion Science and Engineering, USDA-ARS Eastern Regional Research Center, Wyndmoor, Pennsylvania. **Corresponding author:** Radhakrishnan Srinivasan, Department of Agricultural and Biological Engineering, Mississippi State University, Mississippi State, MS 39762; phone: 662-325-8536; fax: 662-325-3853; e-mail: rs634@msstate.edu.

During fuel ethanol production from cereal grains using the conventional dry grind process, the cereal grain is first milled into flour, water is added to the flour, the starch in the slurry is then enzymatically converted to sugars, and the mash is fermented to produce ethanol. The non-starch components of the cereal grain form the coproduct, known as distillers dried grains with solubles (DDGS). DDGS is primarily used as an animal feed.

Beta-glucans are the major non-starch polysaccharides present in various tissues of barley and oats (Izydorczyk and Dexter, 2008). Like starch, they are composed entirely of D-glucose; however, the linkages between the glucose residues are a mixture of β-1,3- and β-1,4- linkages. The presence of beta-glucans in barley is a detriment to the conventional dry grind process because the beta-glucans cause high viscosity problems during fermentation of the mash. In addition, the presence of beta-glucans in DDGS causes anti-nutritional effects when fed to animals (Philip et al., 1995). Recently, the EDGE (enhanced dry grind enzymatic) ethanol process was developed to mitigate the problems caused by beta-glucans (Nghiem et al., 2008). In the EDGE process, β-glucanase enzymes are added during liquefaction to partially hydrolyze β-glucans into β-oligosaccharides and thereby reduce the viscosity of the mash. Next, the enzyme β-glucosidase is added during saccharification and fermentation to convert the non-fermentable β-oligosaccharides, which are formed upon enzymatic hydrolysis of β-glucans, to glucose (Nghiem et al., 2008). The glucose is then readily fermentable by *S. cerevisiae*. The EDGE process decreases the viscosity of mash and decreases the beta-glucan content of DDGS while increasing the ethanol yield from barley due to complete conversion of beta-glucans, in addition to starch. Thus, the EDGE process not only mitigates problems caused by beta-glucans, but also increases fuel ethanol yields.

Recently, it was found that the Elusieve process, which is the combination of sieving and air classification (elutriation or aspiration), was effective in fiber separation from corn flour prior to fermentation (Srinivasan and Singh, 2008). Fiber does not ferment in the dry grind process, and its separation from the flour prior to fermentation increases ethanol productivity during fermentation. In the Elusieve process for corn flour, the flour was sieved into four different sizes, and fiber was separated from the three largest sieve fractions by air classification. The separated fiber could be used as combustion fuel, cattle feed, and for production of valuable products like "cellulosic" ethanol, fiber gum, phytosterols, and polymer composites. Production of ethanol from corn fiber, a cellulosic feedstock, was studied in earlier works, and ethanol yields (90% of theoretical or higher) were comparable to yields from starchy materials (Dien et al., 1999; Srinivasan et al., 2007).

Vose and Youngs (1978) showed that air classification of malted barley and barley flours has the potential of producing starchy flours with low protein and low NDF contents. Sundberg et al. (1995) showed that the combinations of milling, sieving, and air classification could increase beta-glucan content on dry basis from 6.6% of the barley flour to a maximum beta-glucan content of 12.0% in a fraction. Furthermore, it can also increase dietary fiber content (inclusive of beta-glucans) from 18.7% in barley flour to a maximum of 47.7% in a fraction with 0.5 wt% of original flour.

A combination of sieving and air classification, as used in the Elusieve processing of corn flour, could be useful in producing hull-enriched and beta-glucan-enriched fractions from barley flour and would involve fewer processing steps than used by Sundberg et al. (1995). The objective of this study was to determine the effect of Elusieve processing on the compositions of fractions from barley flour.

Materials and Methods

The two varieties of barley studied in this work are Thoroughbred (hulled) and Doyce (hulless), developed by Drs. Wynse Brooks and Carl Griffey at the Virginia Polytechnic Institute and State University (Virginia Tech) and grown at Mt. Holly, Virginia, at the Virginia Crop Improvement Association's Foundation Seed Farm. The flour was prepared by milling each of the barley varieties with a hammer mill (model 10SSMHBD, Glen Mills, Clifton, N.J.) using the 1 mm opening size screen at the USDA-ARS Eastern Regional Research Center (Wyndmoor, Pa.). The entire quantity of grain, within each variety, came from one harvest at one location.

Following the milling, approximately 50 kg of each of the barley flours were sieved using a rectangular rotary sifter (model 484, Gump, Savannah, Ga.) with a sieving area of 1.8 m^2 (19 ft^2) per deck, in which the stack consisted of three decks, to produce four size fractions. The screens used were 30M (680 μm), 40M (470 μm), and 60M (322 μm). The letter "M" refers to market-grade cloth.

The 30M (>680 μm) and 40M (470 to 680 μm) size fractions were air classified using a multi-aspirator (model VJ8X6, Kice, Wichita, Kans.). The multi-aspirator is comprised of a material feeding section through which the size fraction is fed, and an air-inlet section through which air is sucked into the aspirator by a fan. The air carries the lighter particles from the size fraction into the cyclone section. The remaining part of the size fraction (the heavier particles), which is not carried by the air, flows straight through the feeding section into a collection drum. The lighter fraction collects in the bottom of the cyclone section. The air from the cyclone flows out through a filter bag, which is used to retain any residual particles. A butterfly-type damper is available in the air flow duct to adjust the air flow in the aspirator and thus control the yield of lighter fraction from the size fraction.

Experimental Procedure

The four size fractions, 30M (>680 μm), 40M (470 to 680 μm), 60M (322 to 470 μm), and pan (<322 μm), obtained from sieving of 50 kg of barley flour were split into three batches (batches 1, 2, and 3). The 30M (>680 μm) and 40M (470 to 680 μm) size fractions from each batch were air classified to obtain lighter and heavier fractions at three different lighter fraction yields: 5, 10, and 15 wt% from each of the size fractions. The butterfly-type damper in the air flow duct of the multi-aspirator was adjusted by trial and error to control the yield of lighter fraction from the sieve fraction. The 60M (322 to 470 μm) size fraction was not aspirated because aspiration/elutriation is not effective for small size fractions such as 60M (322 to 470 μm), as observed from previous experiences.

The whole barley flour, the size fractions, and the lighter/heavier fractions from air classification were analyzed for chemical composition. Beta-glucan was determined by use of a mixed linkage beta-glucan kit purchased from Megazyme International Ireland, Ltd. (Wicklow, Ireland). The neutral detergent fiber (NDF), starch, protein, fat, ash, and moisture contents were determined by NIR spectroscopy by the Dairy One Forage Laboratory (Ithaca, N.Y.). NDF is used for measuring cellulose, hemicellulose, and lignin content (Van Soest et al., 1991). Complex carbohydrates not measured as NDF are β-glucans, pectins, galactans, other gums, and mucilages (Van Soest et al., 1991).

NDF Separation Factor

The NDF separation factor for aspiration is defined as the ratio of the NDF%/non-NDF% of the lighter fraction to the NDF%/non-NDF% of the heavier fraction (Srinivasan et al., 2005). It is calculated as:

$$\text{NDF separation factor} = \frac{\left[\text{NDF}\,\% / \left(100 - \text{NDF}\,\%\right)\right]_{\text{Lighter fraction}}}{\left[\text{NDF}\,\% / \left(100 - \text{NDF}\,\%\right)\right]_{\text{Heavier fraction}}}$$

The NDF separation factor indicates the selectivity of air in carrying hulls rather than non-hull components at the operating air velocity. A high NDF separation factor indicates that the selectivity of air in carrying hulls is high. The NDF separation factor is analogous to solvent selectivity in liquid extraction and relative volatility in distillation.

Beta-Glucan Separation Factor

The beta-glucan separation factor for aspiration is defined as the ratio of the beta-glucan%/non-beta-glucan% of the heavier fraction to the beta-glucan%/non-beta-glucan% of

Table 1. Yield (wt%) and composition (% d.b.) of Doyce and Thoroughbred (TB) barley size fractions.[a]

Size Fraction	Yield (wt%)		Beta-Glucan		NDF[b]		Starch		Protein		Fat		Ash	
	Doyce	TB	Doyce	TB	Doyce	TB	Doyce	TB	Doyce	TB	Doyce	TB	Doyce	TB
Original	100	100	3.5 a	3.8 a	13.0 a	15.3 cd	59.6 b	60.8 c	11.2 b	9.8 a	2.1 a	2.2 a	2.6 a	2.9 a
30M (>680 µm)	42.6	50.7	3.8 a	4.0 a	13.3 a	13.6 d	58.7 bc	63.4 a	11.8 b	10.1 a	2.3 a	2.3 a	2.7 a	2.3 b
40M (470 to 680 µm)	23.7	20.7	3.8 a	3.6 ab	13.4 a	19.1 ab	56.1 d	57.5 cd	13.0 ab	9.7 a	2.5 a	2.2 a	2.6 a	2.9 a
60M (322 to 470 µm)	7.7	9.3	3.6 a	3.3 b	15.1 a	19.7 a	57.1 c	55.2 d	11.1 b	9.8 a	2.4 a	2.3 a	2.7 a	3.1 a
Pan (<322 µm)	26	19.4	3.4 a	3.2 b	13.5 a	16.3 bc	65.9 a	61.6 b	8.8 c	8.0 b	1.9 a	2.2 a	2.4 a	3.0 a

[a] Values within a column followed by the same letter are not statistically different. COVs for compositions of fractions were less than 13%.
[b] NDF = neutral detergent fiber.

the lighter fraction. The beta-glucan separation factor is the ratio of values for heavier fraction to that for lighter fraction, while the NDF separation factor is the ratio of values for lighter fraction to that for heavier fraction.

Statistical Analyses

The compositions and yields following aspiration are reported as the mean values from the three batches. The COVs of lighter fraction compositions were higher than for heavier fraction compositions because of the lower quantities of lighter fractions available for analyses (tables 2 and 3).

The size fractions obtained from sieving of barley flour were split into three batches for air classification. ANOVA analysis and multiple comparison tests (SAS Institute, Inc., Cary, N.C.) were used to compare means of compositions and yields from processing of three batches. Statistical significance level was 5% ($p < 0.05$).

Results and Discussion

Sieving

For both varieties (Doyce and Thoroughbred), sieving alone resulted in a fraction, the pan fraction (<322 µm), that had higher starch content than the original barley flour (table 1). For Doyce, the pan fraction (<322 µm) comprised 26.0 wt% of the original barley flour and had higher starch content (65.9%) than the original flour (59.6%) (table 1). For Thoroughbred, the pan fraction (<322 µm) comprised 19.4 wt% of the original barley flour and had slightly higher starch content (61.6%) than the original flour (60.8%) (table 1). For Thoroughbred, the pan fraction (<322 µm) had lower beta-glucan content (3.2%) than the original flour (3.8%) (table 1). There was no significant difference in protein, fat, and ash contents of size fractions for Doyce as well as for Thoroughbred (table 1).

Air Classification of Size Fractions

The chemical compositions of lighter and heavier fractions from the 30M (>680 µm) and 40M (470 to 680 µm) size fractions were compared and it was found that, generally, the NDF values of the lighter fractions were higher than the NDF values of corresponding heavier fractions (except for the 26.6 wt% lighter fraction yield from the Doyce 30M [>680 µm] size fraction), signifying preferential carryover of hulls by air (table 2). The NDF separation factors were higher for Thoroughbred (2.6 to 5.0 for 30M [>680 µm] size fraction, and 2.4 to 3.0 for 40M [470 to 680 µm] size fraction) than for Doyce (0.9 to 1.8 for 30M [>680 µm] size fraction, and 1.2 to 1.3 for 40M [470 to 680 µm] size fraction) (fig. 1 and table 2). The beta-glucan contents of the heavier fractions were higher than or similar to the beta-glucan contents of the corresponding lighter fractions for 30M (>680 µm) and 40M (470 to 680 µm) size fractions, signifying preferential retention of beta-glucans in the heavier fractions (table 2). Similar to the NDF separation factor, beta-glucan separation factors were higher for Thoroughbred (1.6 to 2.5 for 30M [>680 µm] size fraction, and 1.8 to 1.9 for 40M [470 to 680 µm] size fraction) than for Doyce (1.1 to 1.2 for 30M [>680 µm] size fraction, and 1.0 to 1.1 for 40M [470 to 680 µm] size fraction) (table 2).

Thoroughbred is a hulled variety, while Doyce is a hulless variety; thus, the higher amounts of hull present in Thoroughbred causes increased carryover of hull into the lighter fractions for Thoroughbred. This phenomenon explains the higher NDF separation factors for Thoroughbred compared to Doyce. The higher beta-glucan separation factors for Thoroughbred compared to Doyce along with the lower beta-glucan contents in lighter fractions indicate that beta-glucans are associated with the non-hull portion of the barley grains.

As observed with NDF and beta-glucan contents, the effects of fractionation were more pronounced in Thoroughbred for protein, fat, and starch contents than in Doyce. In Thoroughbred, starch, protein, and fat contents in heavier fractions were higher than in corresponding lighter fractions because of hull carryover into the lighter fractions (table 3). In Doyce, in most cases, starch, protein, and fat contents of

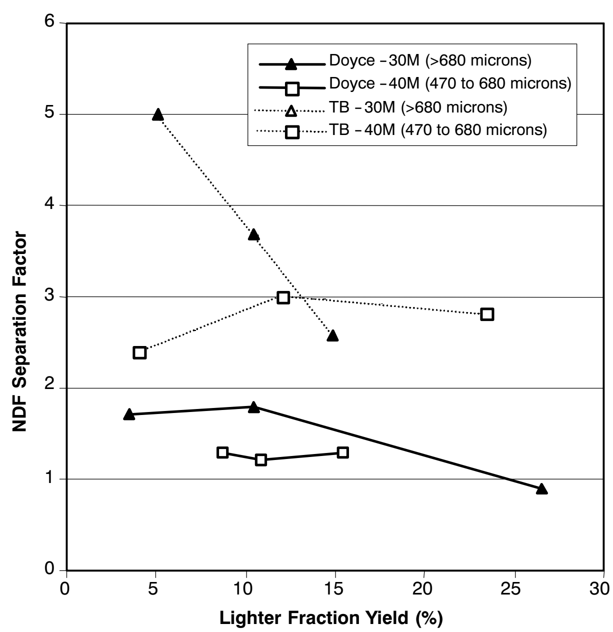

Figure 1. NDF separation factors at various lighter fraction yields for air classification of 30M (>680 µm) and 40M (470 to 680 µm) size fractions of Doyce and Thoroughbred (TB) barley varieties.

Table 2. Effect of increasing yields of the lighter fraction (wt%) on beta-glucan, neutral detergent fiber (NDF), and ash contents (% d.b.) of the lighter and heavier fractions from aspiration of Doyce and Thoroughbred (TB) barley size fractions.[a]

Size Fraction[b]	Lighter Fraction Yield (wt%)		Beta-Glucan						NDF[c]						Ash			
			Doyce			TB			Doyce			TB			Doyce		TB	
	Doyce	TB	L[d]	H	α	L	H	α	L	H	α	L	H	α	L	H	L	H
30M	3.5[e] c	5.1 c	3.1 a	3.7 a	1.2	1.6[g] c	3.8 a	2.5	17.8	11.1 b	1.7	42.6 a	13.0 c	5.0	2.9	2.4 a	4.2 a	2.3 c
	10.5 b	10.5 b	3.1 a	3.7 a	1.2	2.3 b	4.0 a	1.8	20.8[h] a	12.8 b	1.8	34.1 a	12.3 c	3.7	2.9 a	2.3 a	4.3 a	2.1 c
	26.6 a	14.9 a	3.5 a	3.7 a	1.1	2.5 b	4.0 a	1.6	14.6 b	15.9 ab	0.9	25.0 b	11.6 c	2.6	2.6 a	2.4 a	3.0 b	2.2 c
40M	8.7[f] c	4.0[e] c	3.6 a	3.6 a	1.0	2.0 b	3.7 a	1.9	19.1 a	15.3 c	1.3	33.9	17.9 c	2.4	2.6 b	2.7 ab	3.9	2.8 c
	10.8 b	12.1[f] b	3.4 a	3.6 a	1.1	2.0 b	3.6 a	1.9	18.1 b	15.8 cd	1.2	35.0[i] a	15.4 d	3.0	3.0 ab	2.9 a	4.3 a	2.7 b
	15.4 a	23.4[f] a	3.6 a	3.6 a	1.0	2.1 b	3.9 a	1.8	17.1 b	14.1 d	1.3	32.1 b	14.4 d	2.8	2.8 ab	2. 8 ab	4.3 a	2.5 b

[a] Values within a size fraction followed by the same letter are not statistically different. COVs for compositions of heavier fractions were less than 13%. For lighter fractions, the COVs of beta-glucan, NDF, and ash content were less than 22%, 26%, and 18%, respectively.
[b] 30M = >680 µm; 40M = 470 to 680 µm.
[c] NDF = neutral detergent fiber.
[d] L = lighter fraction, H = heavier fraction, and α = separation factor.
[e] Two lighter fraction samples out of the three batches were insufficient for composition analyses, except beta-glucan analyses. Hence, these means do not have any significance letters as suffixes.
[f] One lighter fraction sample out of the three batches was insufficient for composition analyses, except beta-glucan analyses.
[g] COV was 48%.
[h] COV was 40%.
[i] COV was 20%.

Table 3. Effect of increasing yields of the lighter fraction (wt%) on starch, protein, and fat contents (% d.b.) of the lighter and heavier fractions from aspiration of Doyce and Thoroughbred (TB) barley size fractions.[a]

Size Fraction[b]	Lighter Fraction Yield (wt%)		Starch				Protein				Fat			
			Doyce		TB		Doyce)		TB		Doyce		TB	
	Doyce	TB	L[c]	H	L	H	L	H	L	H	L	H	L	H
30M	3.5[d] c	5.1 c	49.6	58.6 a	39.9 c	65.1 a	11.8	11.3 a	6.1 c	9.8 a	3.0	2.3 a	1.2[f] b	2.0 a
	10.5 b	10.5 b	51.9 b	61.5 a	50.1 b	64.8 a	10.5 a	10.7 a	7.4 bc	9.8 a	2.4 a	2.2 a	1.7 ab	1.9 a
	26.6 a	14.9 a	58.5 a	57.4 a	54.9 b	65.5 a	11.2 a	10.8 a	8.2 ab	10.0 a	2.4 a	2.4 a	1.9 a	2.1 a
40M	8.7[e] c	4.0[d] c	56.7 a	52.8 a	46.5	57.6 b	9.8 c	11.7 abc	7.7	9.6 a	2.2 a	2.7 a	1.8	2.4 a
	10.8 b	12.1[e] b	54.3 a	54.9 a	48.2 c	57.5 a	11.2 abc	11.7 ab	7.7 b	10.4 a	2.7 a	2.7 a	1.9 b	2.3 ab
	15.4 a	23.4[e] a	55.7 a	55.4 a	48.5 c	59.5 a	10.3 bc	12.3 a	8.2 b	10.0 a	2.5 a	2.7 a	2.1 ab	2.3 a

[a] Values followed by the same letter within a size fraction are not statistically different. COVs for compositions of heavier fractions were less than 13%. For lighter fractions, the COVs of starch, protein, and fat contents were less than 13%, 27%, and 24%, respectively.
[b] 30M = >680 µm; 40M = 470 to 680 µm.
[c] L= lighter fraction; H = heavier fraction.
[d] Two lighter fraction samples out of the three batches were insufficient for composition analyses. Hence, these means do not have any significance letters as suffixes.
[e] One lighter fraction sample out of the three batches was insufficient for composition analyses.
[f] COV was 48%.

heavier fractions were slightly higher or the same as for corresponding lighter fractions because separation is not as effective for Doyce since it is a hulless variety (table 3).

Ash contents had similar trends as NDF contents. For Thoroughbred, ash contents were higher in the lighter fractions than in the heavier fractions. For Doyce, ash contents were higher or same in the lighter fractions than in the heavier fractions (table 2).

Thus, the heavier fractions contain higher levels of beta-glucan and starch, and lower levels of NDF, than the corresponding lighter fractions. Elusieve fractionation of barley flour, especially hulled varieties, could be beneficial, especially when combined with in the enzymatic dry grind ethanol (EDGE) process, because both the beta-glucans and starch would be converted to ethanol. The increase in beta-glucan and starch contents in barley flour, by hull separation, could increase ethanol productivity and decrease the fiber content in resulting distillers dried grains with solubles (DDGS), thus increasing DDGS utilization in non-ruminant animals. If Elusieve fractionation is added to a dry grind ethanol plant producing 640 m^3 per day (60 million gallons per year) of fuel ethanol, then the additional cost of electric energy for air classification of barley size fractions is nominal ($27,450 per year) based on use of three multi-aspirators, each needing a 22.4 kW (30 hp) motor, and cost of $0.05 per kWh for electricity (Srinivasan et al., 2006).

Effect of Lighter Fraction Yields

Since Elusieve fractionation was less effective for Doyce due to its being hulless, we discuss the effect of lighter fraction yields on the compositions of fractions for Thoroughbred only. For Thoroughbred; as the yield of the lighter fraction increased, the NDF of heavier fractions decreased (table 2). Due to the increased removal of hulls during aspiration, the NDF in the lighter fractions decreased or remained same because of increased carryover of non-hull components into the lighter fractions (table 2). These findings are similar to results observed for the Elusieve process in fiber separation from DDGS (Srinivasan et al., 2005). For the 30M (>680 µm) size fraction of Thoroughbred, as the lighter fraction yield increased from 10.5% to 14.9%, the NDF values of heavier fractions were not different (12.3% and 11.6%), and the NDF values of the corresponding lighter fractions decreased from 34.1% to 25.0% (table 2).

For Thoroughbred, the levels of beta-glucan in the heavier fractions increased or remained the same, and the beta-glucan content of the lighter fractions increased or remained the same, as lighter fraction yield increased within each size fraction (table 2). For the 30M (>680 μm) size fraction of Thoroughbred, as the lighter fraction yield increased from 5.1% to 10.5%, the beta-glucan contents of heavier fractions were not different (3.8% and 4.0%), and the beta-glucan contents of corresponding lighter fractions increased from 1.6% to 2.3% (table 2).

The levels of starch in the heavier fractions remained the same or increased, and the starch content of the lighter fractions increased, as the lighter fraction yield increased within each size fraction (table 3). The starch content of the heavier fraction of the 30M (>680 μm) size fraction remained the same (65.1%, 64.8%, and 65.5%) as the lighter fraction yield increased from 5.1% to 10.5% to 14.9%, while the starch content of the lighter fraction increased from 39.9% to 50.1% to 54.9% (table 3). Thus, removing only 5 wt% as lighter fraction is sufficient to enrich the 30M (>680 μm) heavier fraction with starch, which will keep the starch loss in the lighter fraction to a minimum. For the 40M (470 to 680 μm) size fraction of Thoroughbred, as the lighter fraction yield increased from 4.0% to 12.1%, the starch contents of the heavier fractions were not different (57.6% and 57.5%) and the starch contents of the corresponding lighter fractions increased from 46.5% to 48.2% (table 3).

The levels of protein and fat of the heavier fractions remained the same or increased due to increased removal of hulls during aspiration as the lighter fraction yield increased within each size fraction. In addition, the protein and fat contents of the lighter fractions increased or remained same because of increased carryover of non-hull components into the lighter fractions. These results are similar to results observed for the Elusieve process in fiber separation from DDGS (table 3) (Srinivasan et al., 2005). For the 30M (>680 μm) size fraction of Thoroughbred, as the lighter fraction yield increased from 5.1% to 10.5%, the protein contents of the heavier fractions were not different (9.8%) and the protein contents of corresponding lighter fractions increased from 6.1% to 7.4% (table 3). For the 30M (>680 μm) size fraction of Thoroughbred, as the lighter fraction yield increased from 5.1% to 14.9%, the fat contents of the heavier fractions were not different (2.0% and 2.1%) and the fat contents of the corresponding lighter fractions increased from 1.2% to 1.9% (table 3).

Comparison of Results to Earlier Barley Fractionation Studies

Comparisons are carried out in this section for results of Thoroughbred variety with results for hulled barley varieties from earlier fractionation studies. Comparisons are not carried out for Doyce variety because fractionation was not effective for the hulless Doyce variety in this work. In this study, the highest NDF from Thoroughbred was 42.6% for the lighter fraction from air classification of the 30M (>680 μm) size fraction at 3.5% yield of lighter fraction (table 2). This lighter fraction with the highest NDF of 42.6% was 1.1 wt% of the original flour, which had an NDF of 15.3% (tables 1 and 2). This compares well with results obtained by Sundberg et al. (1995), in which the fraction with maximum NDF of 47.7% was 0.5 wt% of the original flour, which had NDF of 18.7%.

In this study, the fractions with high starch content, which were the heavier fractions from air classification of size fractions, also had high beta-glucan content. The maximum starch content from Thoroughbred was 65.5% in the heavier fraction from air classification of the 30M (>680 μm) size fraction at lighter fraction yield of 26.6% (table 3). The heavier fraction with 65.5% starch content had a beta-glucan content of 4.0% and was 13.5 wt% of the original barley flour, which had a starch content of 60.8% and beta-glucan content of 3.8% (tables 1, 2, and 3). Earlier studies on fractionation of hulled barley produced fractions that had starch contents as high as 80% or more, and had substantially lower beta-glucan contents than the original flour; the fractions with high starch contents were 11 to 36 wt% of the original barley flour on wet basis (Andersson et al., 2000; Flores et al., 2005; Wu et al., 1994).

Conclusions

The fractionation of barley flour, using the Elusieve process, was more effective for Thoroughbred, a hulled variety, than for Doyce, a hulless variety. The heavier fractions from aspiration of the two largest size fractions contained higher levels of beta-glucan and starch and lower levels of NDF than the corresponding lighter fractions. The increase in beta-glucan and starch contents in barley flour, by hull separation using the combination of sieving and air classification, may increase ethanol productivity and may be beneficial in fuel ethanol production from barley when using a process that converts both starch and beta-glucans into fuel ethanol. Since the Elusieve process was most effective only when hulls were present, any dehulling operation prior to grinding would make Elusieve processing needless.

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